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LOW-SUBSONIC AERODYNAMIC CHARACTERISTICS OF A SPACE SHUTTLE-ORBITER CONCEPT WITH A BLENDED DELTA WING-BODY

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16. Abstract

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SUMMARY

An investigation has been conducted in the Langley low-turbulence pressure tunnel to determine the longitudinal and lateral-directional aerodynamic characteristics of an orbiter model at low subsonic speeds. The configuration was a blended wing-body with a delta planform and was representative of a proposed high-cross-range space shuttle-orbiter. The model had a leading-edge sweep of 67.5° and tip fins having 5° toe-in and 15° roll-out. The model was tested over a range of Reynolds number, based on body length, from about 5.11×10^{6} to 30.59×10^{6}, at Mach numbers less than 0.35, and at angles of attack from about -4° to 20°.

The results of the investigation indicate that increasing the Reynolds number had relatively small effects on the longitudinal aerodynamic characteristics of the model. The model was longitudinally stable up to angle of attack of about 10° (center of gravity at 66.7 percent body length) and neutrally stable throughout the remainder of the test angle-of-attack range. Low values of elevon effectiveness were noted with attendant large elevon deflections required to trim the model; this resulted in a low maximum trim lift coefficient of about 0.15 and a lift-drag ratio of less than 4 for an elevon deflection of -30°. The model was directionally stable up to an angle of attack of 14° and had large positive effective dihedral throughout most of the test angle-of-attack range.

INTRODUCTION

One of the current major goals of NASA and the aerospace industry is the development of a space transportation system capable of placing large payloads in near-earth orbit. As part of this general effort wind-tunnel tests have recently been made at Langley Research Center on a 0.013-scale model of a typical blended delta wing-body concept representative of a high-cross-range orbiter. The present investigation conducted in the Langley low-turbulence pressure tunnel consisted of tests to determine the basic low-subsonic longitudinal and lateral-directional aerodynamic characteristics and longitudinal control effectiveness of the model. The model was tested over a range of Reynolds number, based on body length, from 5.11×10^6 to 30.59×10^6, at Mach numbers less than 0.35, at angles of attack from approximately -4° to 20°, and at angles of sideslip of 0° and -6°.

SYMBOLS

The longitudinal data are referred to the stability system of axes and the lateral-directional data are referred to the body system of axes. (See fig. 1.) The moment center was located at 66.7 percent body length as presented in figure 2. The data were obtained in U.S. Customary Units but are presented in both U.S. Customary Units and the International System of Units (SI). The equivalent values were determined by using the conversion factors given in reference 1.

b wing span, 35.66 cm (14.04 in.)

C_D drag coefficient, Drag/qS

C_L lift coefficient, Lift/qS

C_l rolling-moment coefficient, M_X/qSb

$C_{l_\beta} = \frac{\Delta C_l}{\Delta \beta}$ per deg (where $\beta = -6^{\circ}$ and 0°)

C_m pitching-moment coefficient, M_Y/qSl

$C_{m,o}$ pitching-moment coefficient at $C_L = 0$

C_n yawing-moment coefficient, M_Z/qSb

$C_{n_\beta} = \frac{\Delta C_n}{\Delta \beta}$ per deg (where $\beta = -6^{\circ}$ and 0°)

C_{p_b} base-pressure coefficient

C_Y lateral-force coefficient, F_Y/qS

$C_{Y_\beta} = \frac{\Delta C_Y}{\Delta \beta}$ per deg (where $\beta = -6^{\circ}$ and 0°)

D drag force, N (lb)

F_Y lateral force, N (lb)

l body length, 66.29 cm (26.10 in.)

L lift force, N (lb)

L/D lift-drag ratio

M_X rolling moment, m-N (in-lb)

M_Y pitching moment, m-N (in-lb)

M_Z yawing moment, m-N (in-lb)

q dynamic pressure, N/m^2 (lb/ft^2)

R Reynolds number based on l

S total planform area, 0.121 m^2 (1.302 ft^2)

y distance along Y-axis, cm (in.)

X, Y, Z body reference axes

α angle of attack, deg

β angle of sideslip, deg

δ_e elevon deflection, positive when trailing edge is down, deg

Subscript:

s denotes stability axes

DESCRIPTION OF MODEL

The model tested was an approximate 0.013-scale model of a conceptual high-cross-range orbiter. The general arrangement of the model is shown in figure 2(a) and the wing cross sections are presented in figure 2(b). A photograph of the model is presented in figure 3. The model had a leading-edge sweep of 67.5° and tip fins having 5° toe-in and 15° roll-out. Elevon surfaces served both for pitch and roll control, and the fins had rudders for directional control.

APPARATUS AND METHODS

The tests were conducted in the Langley low-turbulence pressure tunnel which is a variable-pressure, single-return facility having a closed test section 0.91 meter (3.0 feet) wide and 2.3 meters (7.5 feet) high. The tunnel can accommodate tests in air at Reynolds numbers up to approximately 49.2×10^6 per meter (15.0×10^6 per foot) at Mach numbers up to about 0.40.

TEST CONDITIONS

The tests of the present investigation were made at Reynolds numbers, based on body length, from 5.11×10^6 to 30.59×10^6 at Mach numbers up to 0.35. The angle of attack varied from about -4° to 20°. Sideslip data were measured at a sideslip angle of -6°. All tests were made without transition strips on the model.

MEASUREMENTS AND CORRECTIONS

The drag coefficients presented represent gross drag in that base drag has not been subtracted. Base pressures measured during the test are presented in figure 4. The data have been corrected for blockage and lift interference by the methods of references 2 and 3. Angles of attack have been corrected for the effects of balance and sting deflections due to aerodynamic loads.

RESULTS AND DISCUSSION

Static Longitudinal Characteristics

Effect of Reynolds number.- Increasing the Reynolds number from 5.11×10^6 to 30.59×10^6 (fig. 5) had relatively small effects on the aerodynamic characteristics of the model with the exception of L/D. There were no significant effects of Reynolds number on the static longitudinal stability of the model (figs. 5(c) and 5(d)); however, increasing the Reynolds number up to 30×10^6 resulted in small increases in lift-curve slope, increases in base-pressure coefficient, and consistent increases in maximum L/D. The increase in the base pressure is attributed to a reduction in the amount of flow separation on the curvature of the body boattail at the higher Reynolds numbers. The increases in L/D can be attributed to increased lift-curve slope, reduction in skin friction, and an increase in the effective leading-edge suction as the Reynolds number increased. Based on these results and the fact that above 15×10^6 the Reynolds number effects were small, the remainder of the tests were run at a Reynolds number of approximately 15×10^6.

Elevon effectiveness.- The data of figure 6 show that the model is statically longitudinally stable in the angle-of-attack range up to about 10° (center of gravity at $0.667l$) and neutrally stable throughout the rest of the test angle-of-attack range. The basic configuration (i.e., $\delta_e = 0^\circ$), however, exhibited large out-of-trim pitching moments. The data indicate that large deflections of the elevons are required to trim the model because of the large negative values of $C_{m,o}$ and low values of control effectiveness. For the largest deflection (-30°) tested, the model trimmed at a lift coefficient of about 0.15 at an angle of attack of 7°, and the values of L/D were reduced from 8 to about 3.5. These low values of attainable L/D and C_L would result in very high landing sink rates and approach speeds.

Effect of tip fins.- In a brief study to examine reasons for the large negative $C_{m,o}$, tests were made with the tip fins removed. These data are presented in figure 7 and show a decrease in the negative $C_{m,o}$ of about 0.03. The data also indicate a decrease in lift-curve slope as expected as well as a loss in longitudinal stability and elevon effectiveness. Similar results have been shown in past investigations of this type configuration. (For example, see refs. 4 to 8.) The increased negative $C_{m,o}$ with the tip fins on is attributed to the increased negative pressure on the rear portion of the wing, with the fins acting as end plates and in effect blocking the tip vortex.

Static Lateral-Directional Characteristics

The static lateral-directional stability parameters of the model with and without tip fins are presented in figure 8. The data presented were determined from the incremental differences in C_l, C_n, and C_Y measured over the test angle-of-attack range at fixed sideslip angles of 0° and -6°. The data show that the model with tip fins on was directionally stable $\left(+C_{n_\beta}\right)$ up to an angle of attack of about 14° and had large positive effective dihedral $\left(-C_{l_\beta}\right)$ throughout most of the test angle-of-attack range. Past experience with highly swept vehicles has shown that large negative values of C_{l_β} are undesirable and can cause the vehicle to exhibit a Dutch roll oscillation and therefore poor dynamic lateral-directional characteristics. The data for the model with tip fins removed show as expected a loss of directional stability and a resultant decrease in the positive effective dihedral.

SUMMARY OF RESULTS

An investigation has been conducted to determine the low-subsonic aerodynamic characteristics of a proposed space shuttle-orbiter, which is a blended delta wing-body.

The results of the tests on a 0.013-scale model of the vehicle may be summarized as follows:

(1) The effect of Reynolds number on the longitudinal aerodynamic characteristics of the model are relatively small for a range of Reynolds number, based on body length, from 5.11×10^6 to 30.59×10^6.

(2) The model was statically longitudinally stable about the test center of gravity (66.7 percent body length) up to an angle of attack of about 10° and neutrally stable throughout the rest of the test angle-of-attack range. The large negative pitching-moment coefficient at zero lift $C_{m,o}$ of the model required large negative elevon deflections to trim; this resulted in a trim lift coefficient of 0.15 and a lift-drag ratio of 3.5 for an elevon deflection of -30°.

(3) Removing the tip fins reduced the negative $C_{m,o}$ by 0.03; however, it also reduced the lift-curve slope and made the model longitudinally unstable.

(4) With the tip fins installed the model was directionally stable up to an angle of attack of 14° and had a large positive effective dihedral $\left(-C_{l_\beta}\right)$ throughout most of the test angle-of-attack range. Removing the fins made the model directionally unstable throughout the test angle-of-attack range.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., November 16, 1970.

REFERENCES

1. Mechtly, E. A.: The International System of Units – Physical Constants and Conversion Factors (Revised). NASA SP-7012, 1969.

2. Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, With Consideration of the Effect of Compressibility. NACA Rep. 995, 1950. (Supersedes NACA RM A7B28.)

3. Garner, H. C.; Rogers, E. W. E.; Acum, W. E. A.; and Maskell, E. C.: Subsonic Wind Tunnel Wall Corrections. AGARDograph 109, 1966.

4. Ware, George M.; and Shanks, Robert E.: Investigation of the Low Subsonic Stability and Control Characteristics of a Model of a Hypersonic Boost-Glide Airplane Designed for High Lift-Drag Ratios at Low Speeds. NASA TM X-534, 1961.

5. Shanks, Robert E.: Effect of Wing Crank and Sweepback on the Low Subsonic Stability and Control Characteristics of a Model of a Hypersonic Boost-Glide Type Airplane. NASA TM X-181, 1960.

6. Shanks, Robert E.; and Ware, George M.: Investigation of the Flight Characteristics of a 1/5-Scale Model of a Dyna-Soar Glider Configuration at Low Subsonic Speeds. NASA TM X-683, 1962.

7. Ware, George M.; and Shanks, Robert E.: Investigation of the Low-Subsonic Flight Characteristics of a Model of a Reentry Configuration Having a 75° Delta Wing. NASA TM X-684, 1962.

8. Shanks, Robert E.: Investigation of the Low Subsonic Stability and Control Characteristics of a Hypersonic Boost-Glide Type Airplane With Wing, Fuselage, and Vertical-Tail Modifications. NASA TM X-450, 1961.

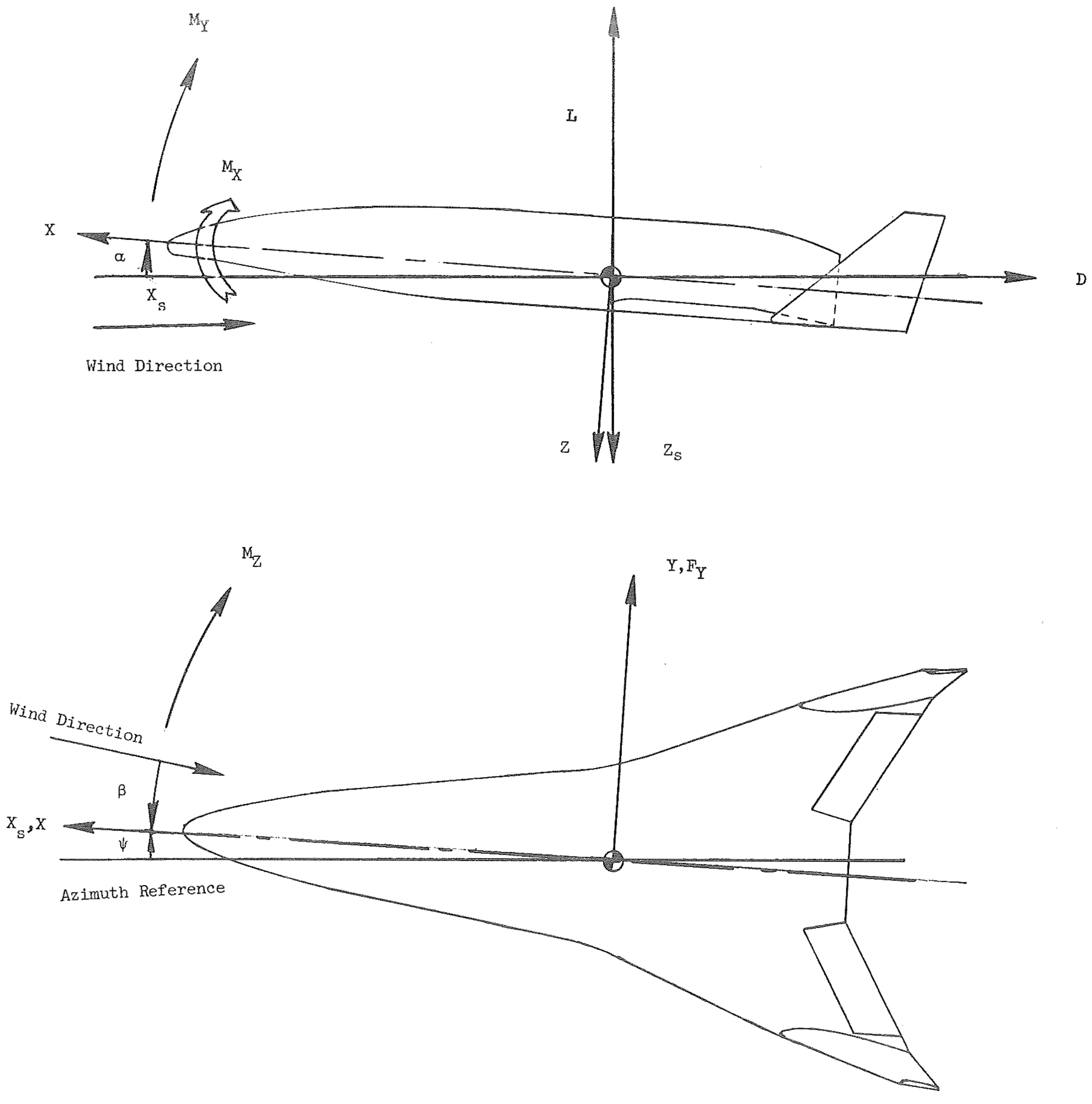
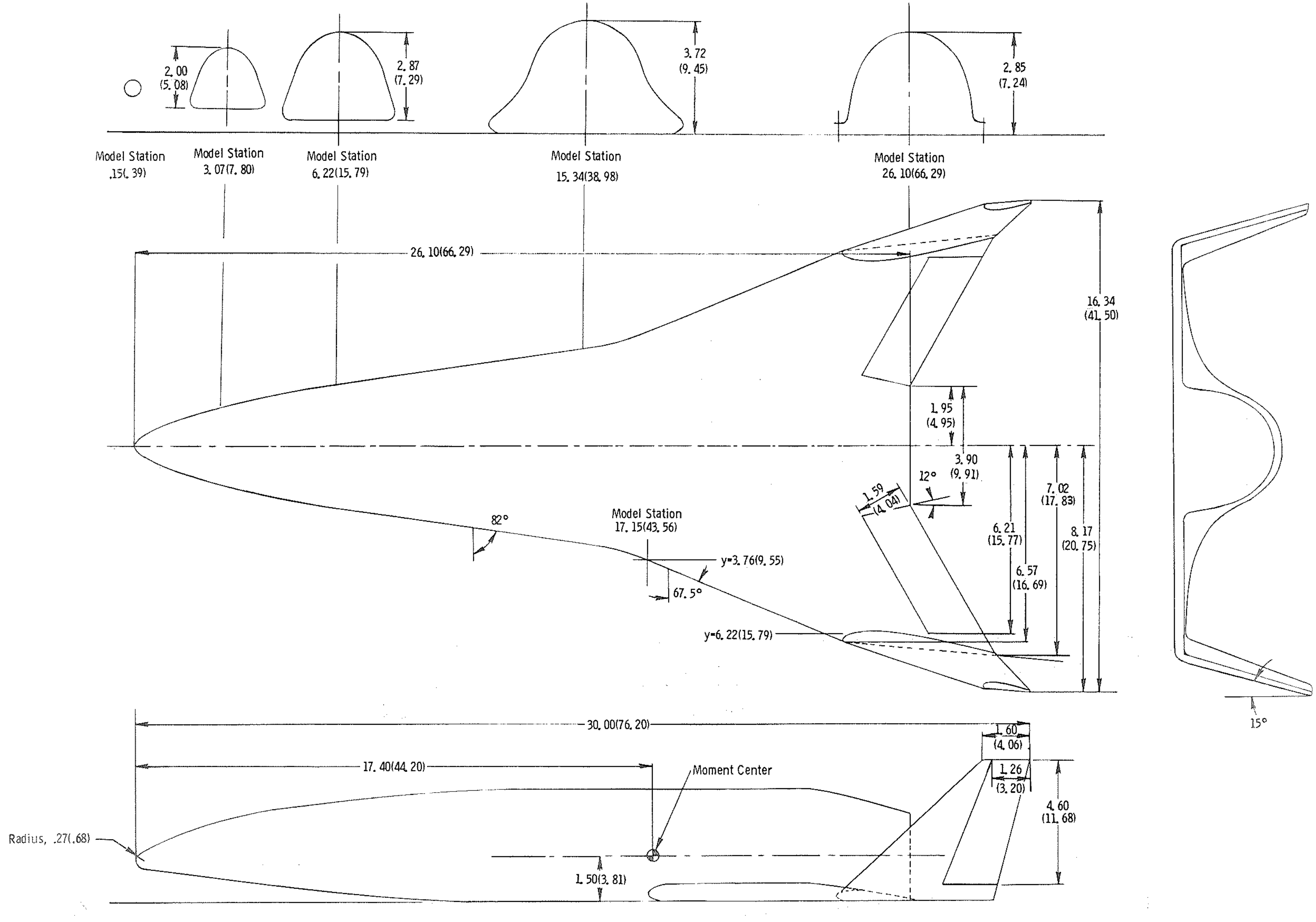
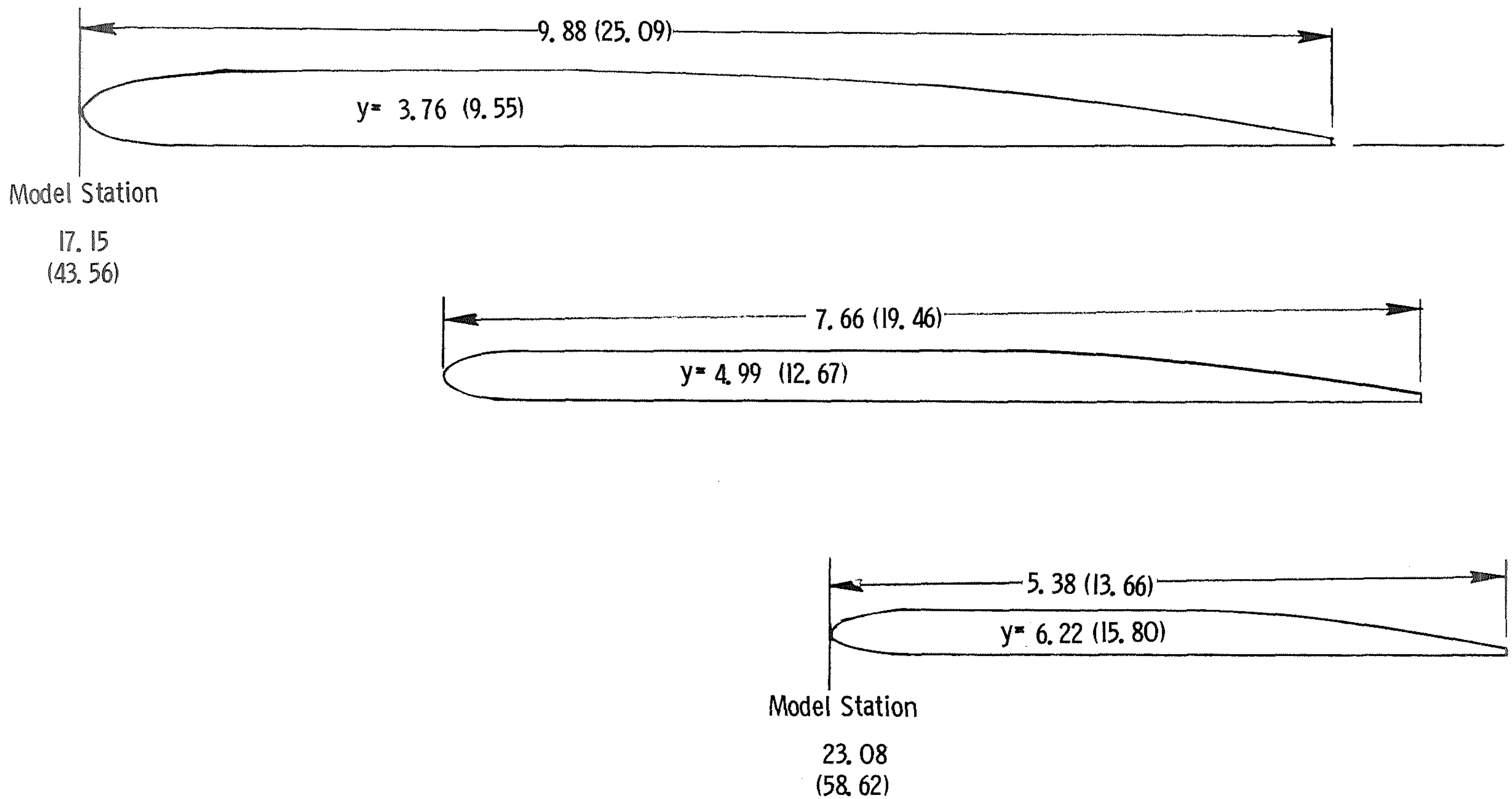


Figure 1.- System of axes used in investigation. Arrows indicate positive directions of moments, forces, axes, and angles.



(a) Three-view drawing of the model.

Figure 2.- Detail drawings of the model. Linear dimensions are in inches with centimeters given in parentheses.



(b) Wing cross sections.

Figure 2.- Concluded.

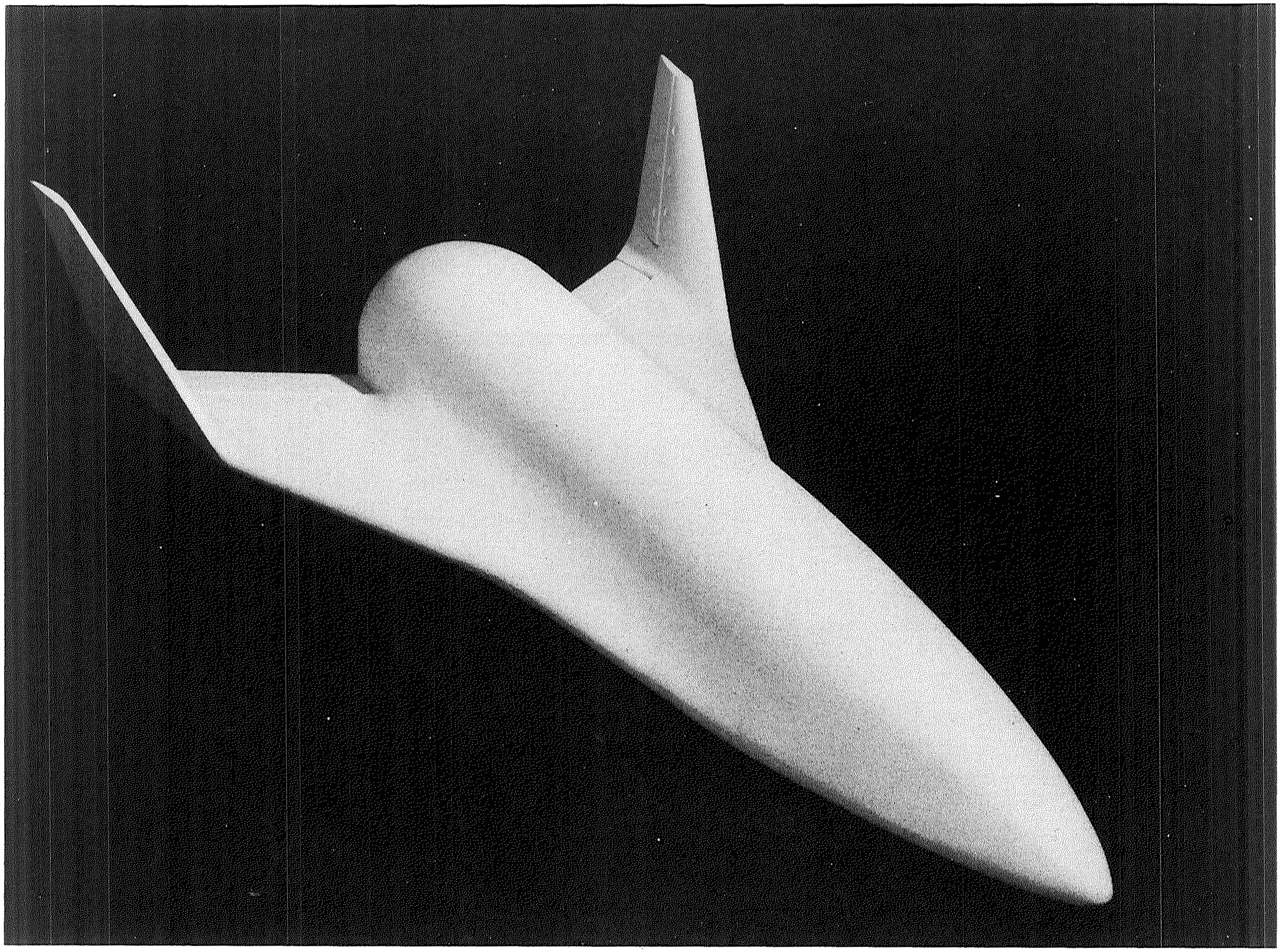


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Figure 3.- Photograph of the model.

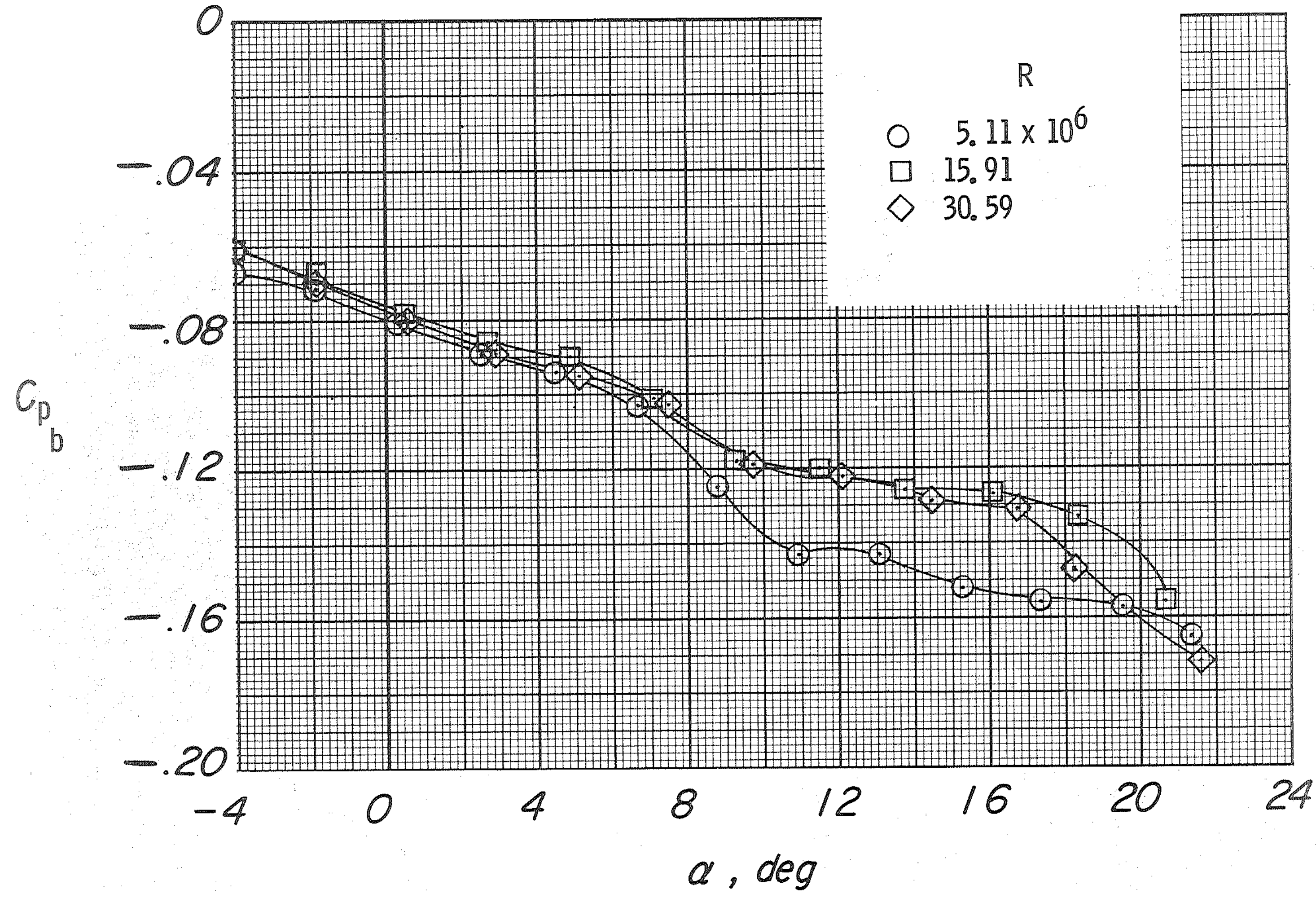
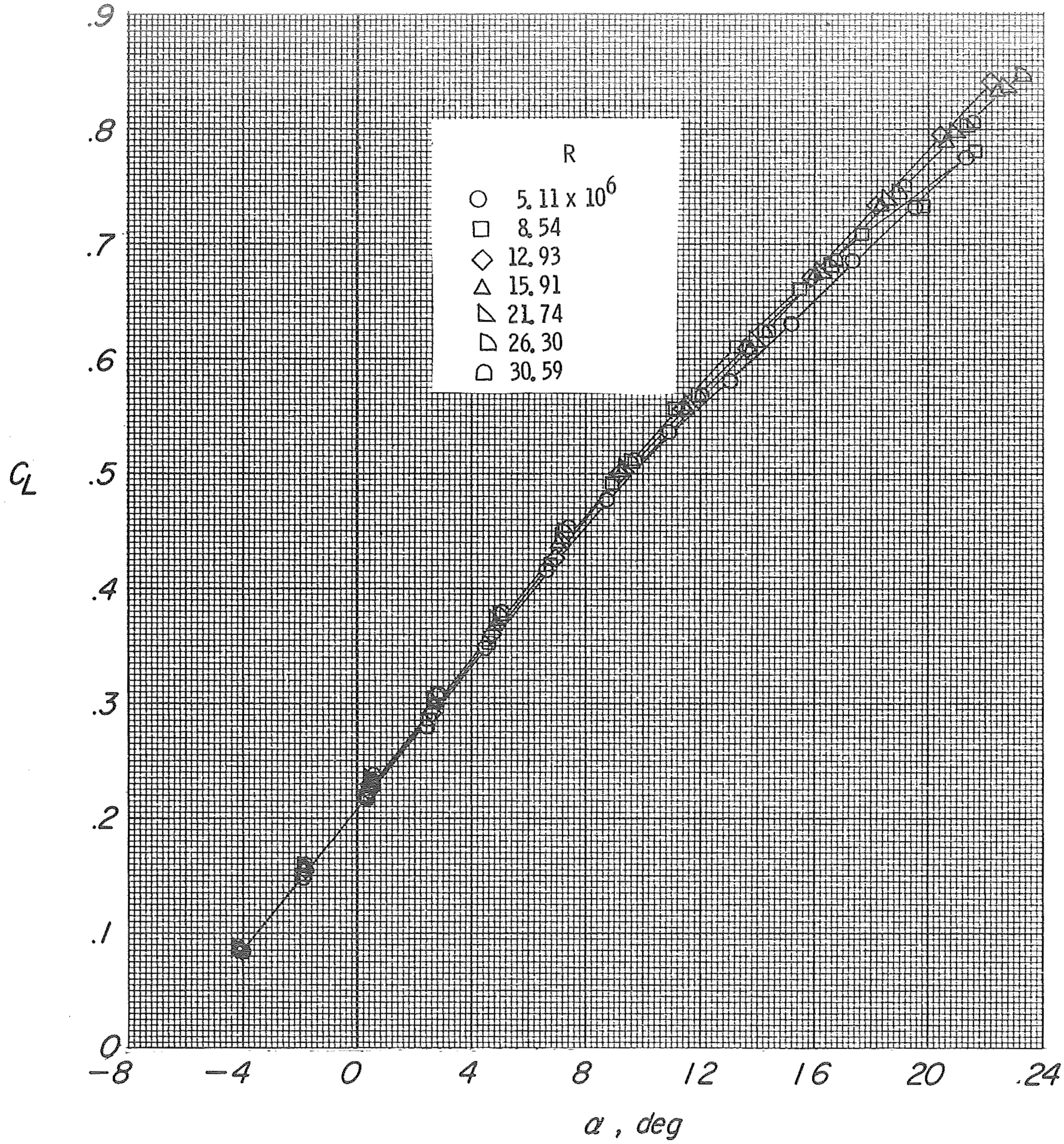
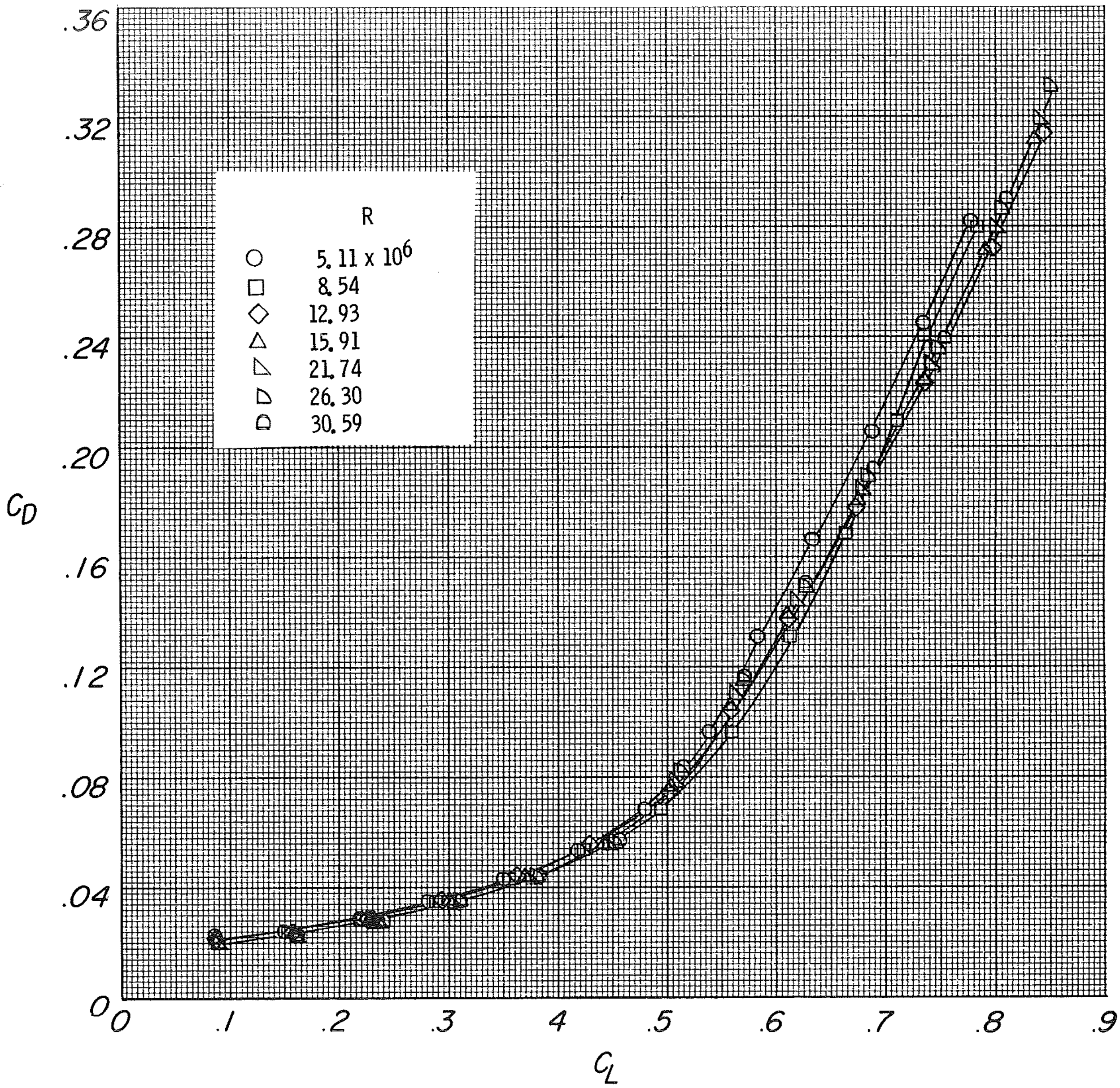


Figure 4.- Base-pressure coefficients of the model. $\delta_e = 0^o$.



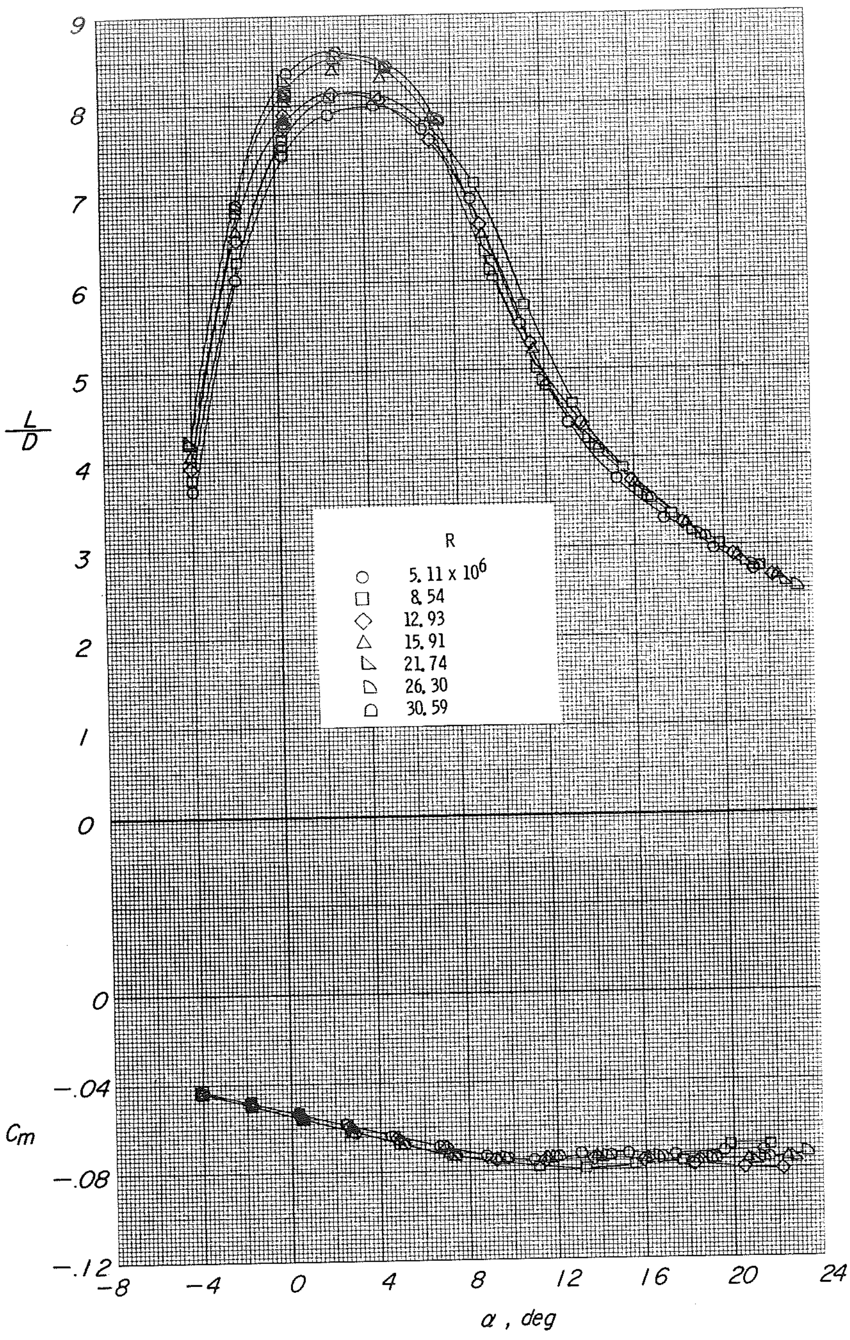
(a) Lift.

Figure 5.- Effect of Reynolds number on the low subsonic aerodynamic characteristics of the model. $\delta_e = 0^{\circ}$.



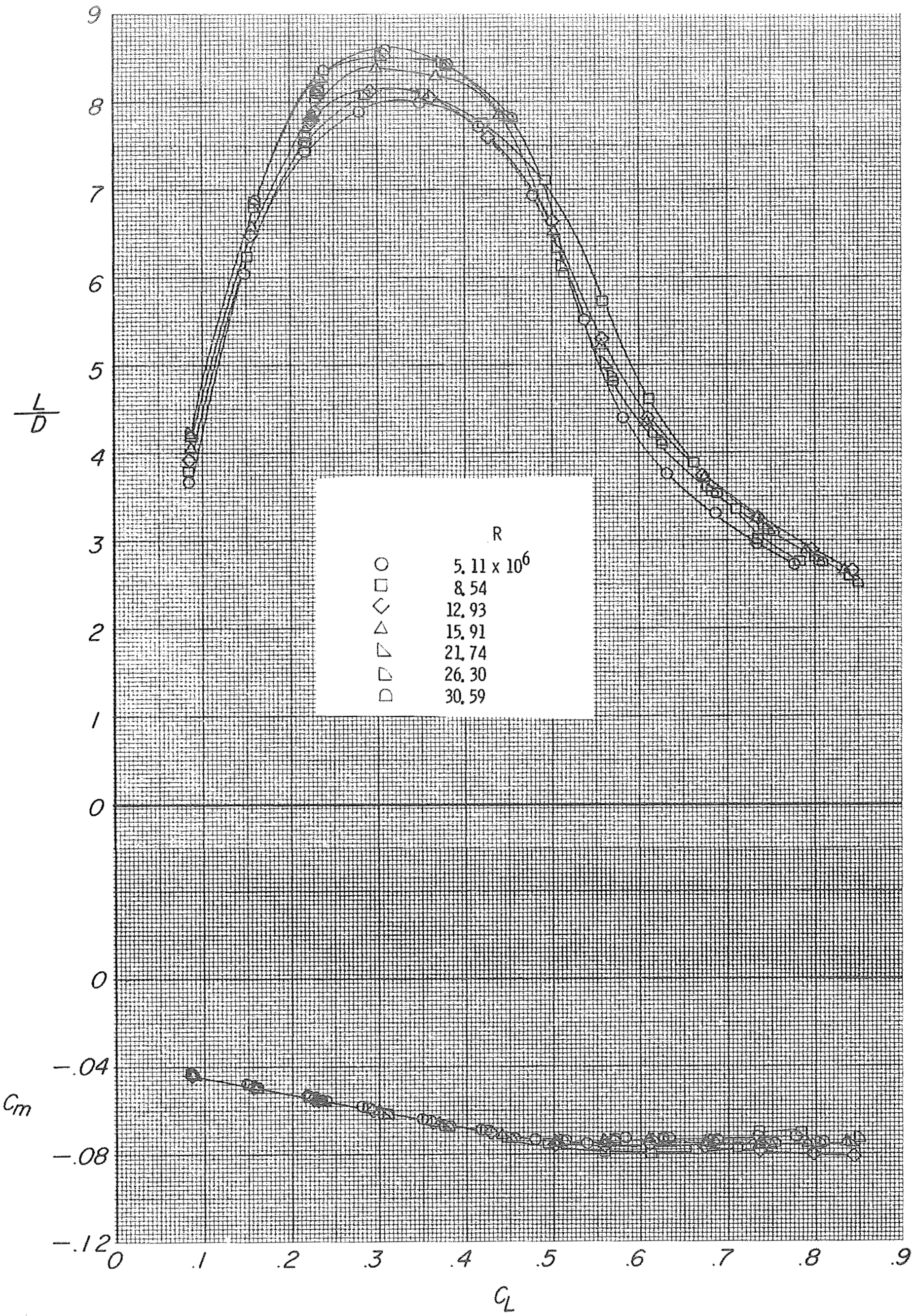
(b) Drag.

Figure 5.- Continued.



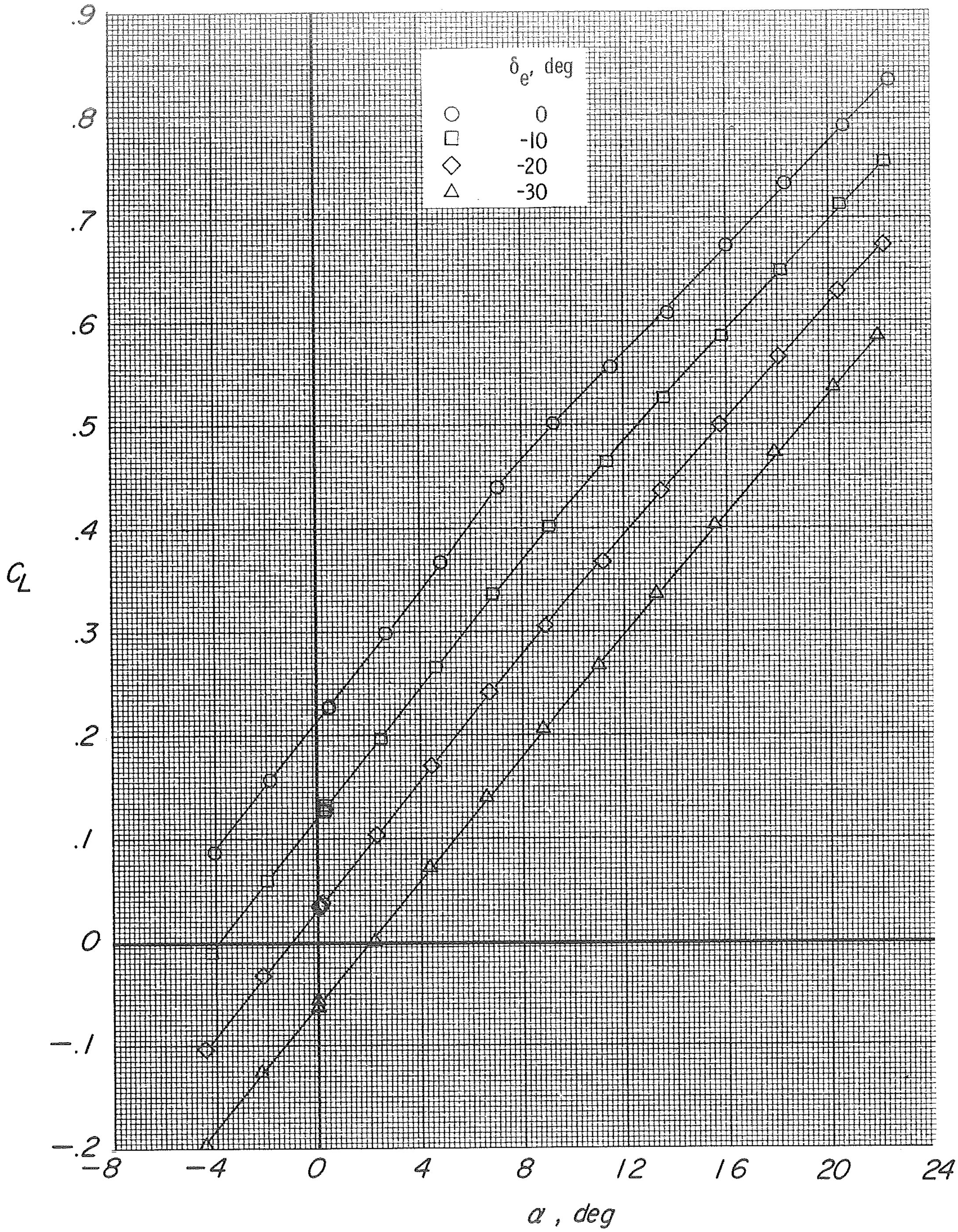
(c) L/D and C_m versus α.

Figure 5.- Continued.



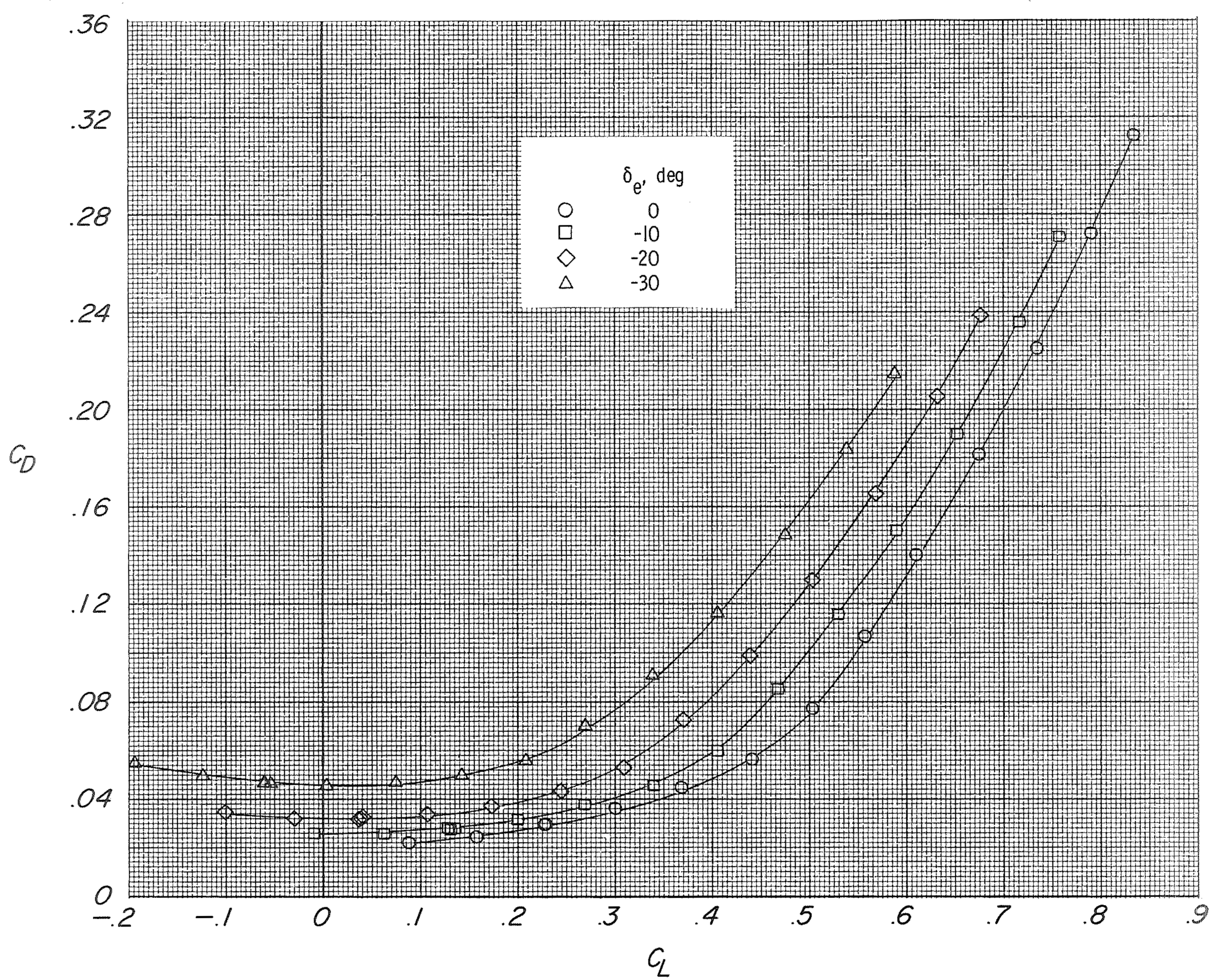
(d) L/D and C_m versus C_L.

Figure 5.- Concluded.



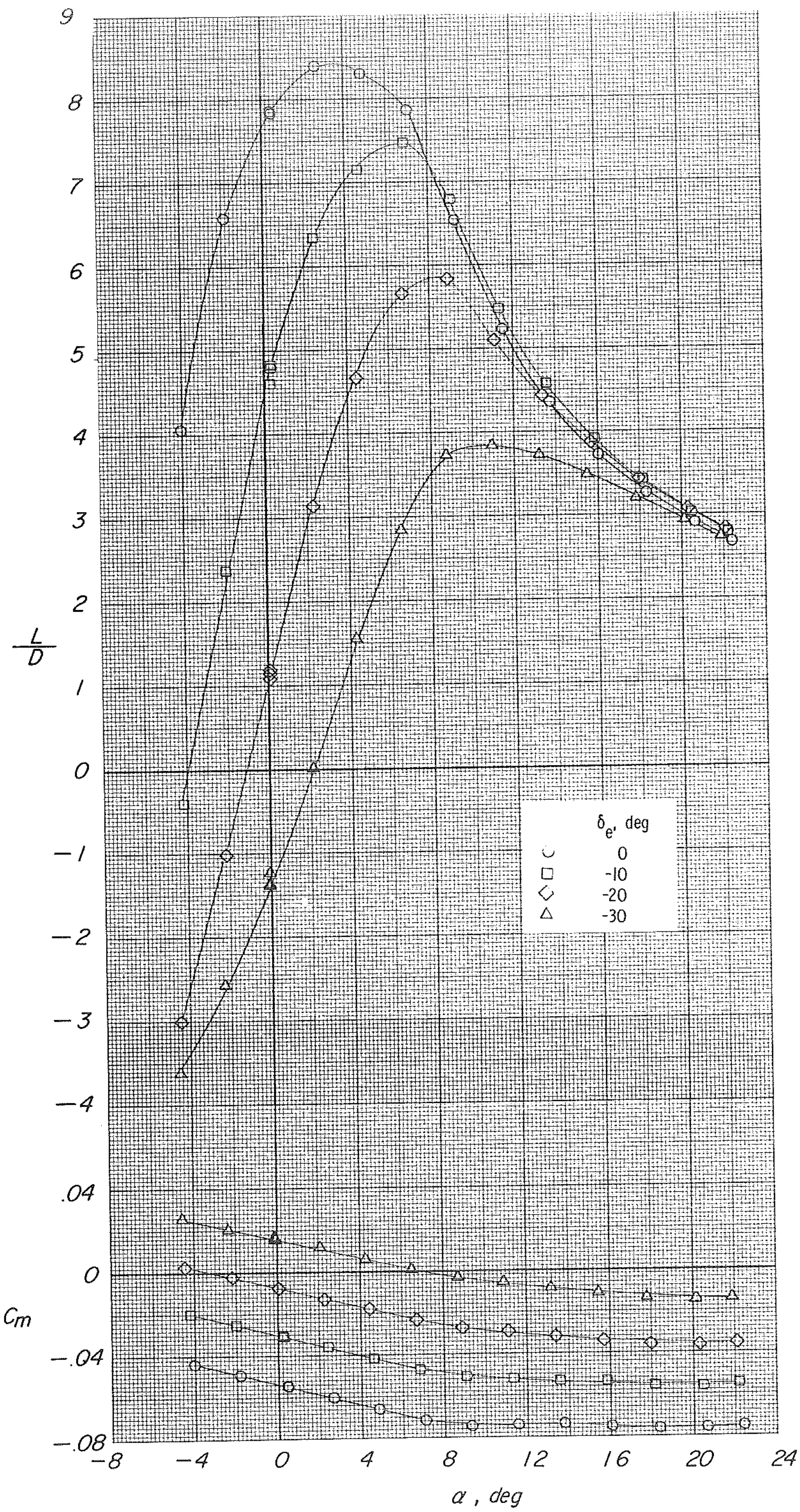
(a) Lift.

Figure 6.- Elevon effectiveness for longitudinal trim. $R = 15.91 \times 10^6$.



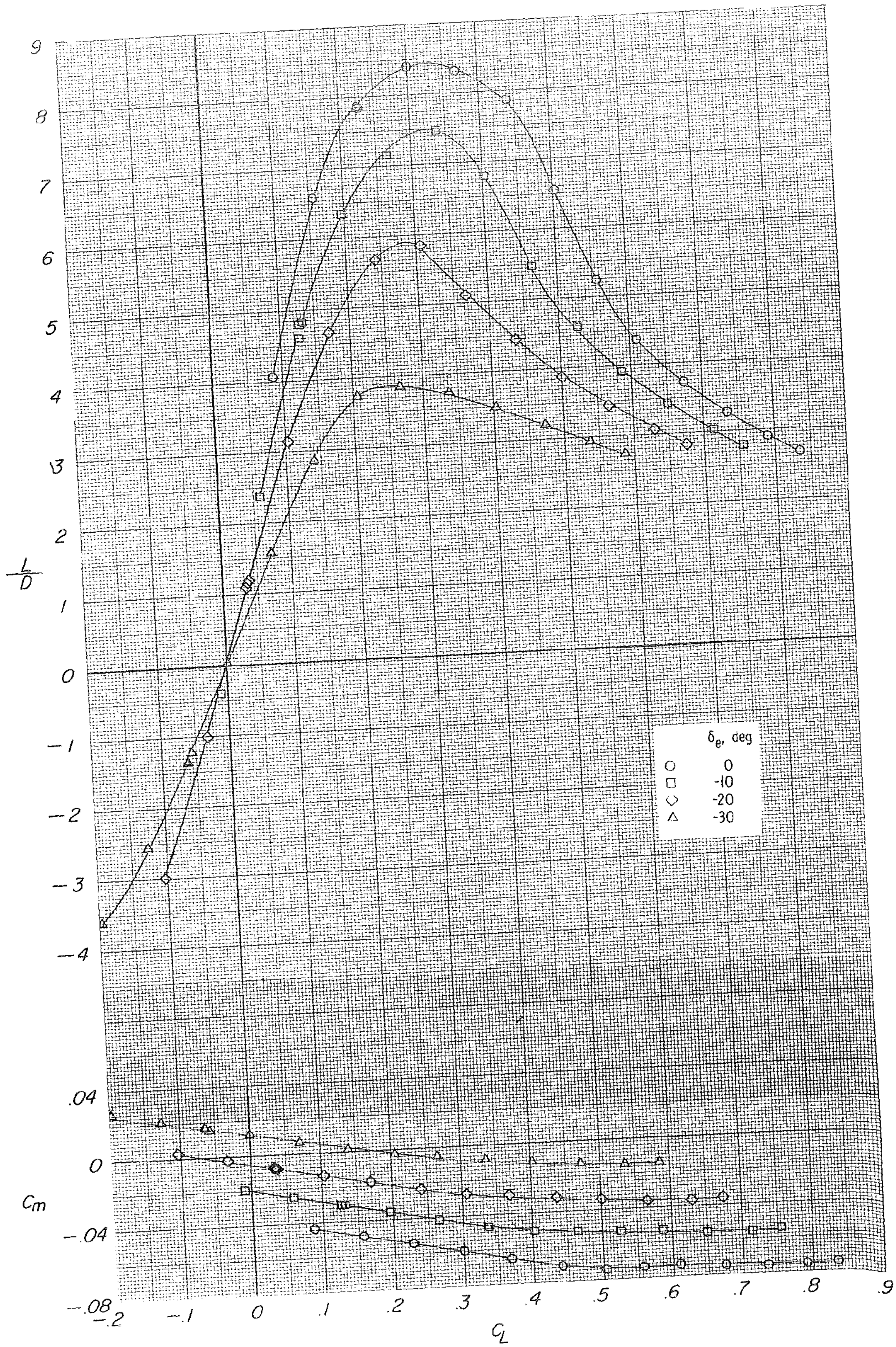
(b) Drag.

Figure 6.- Continued.



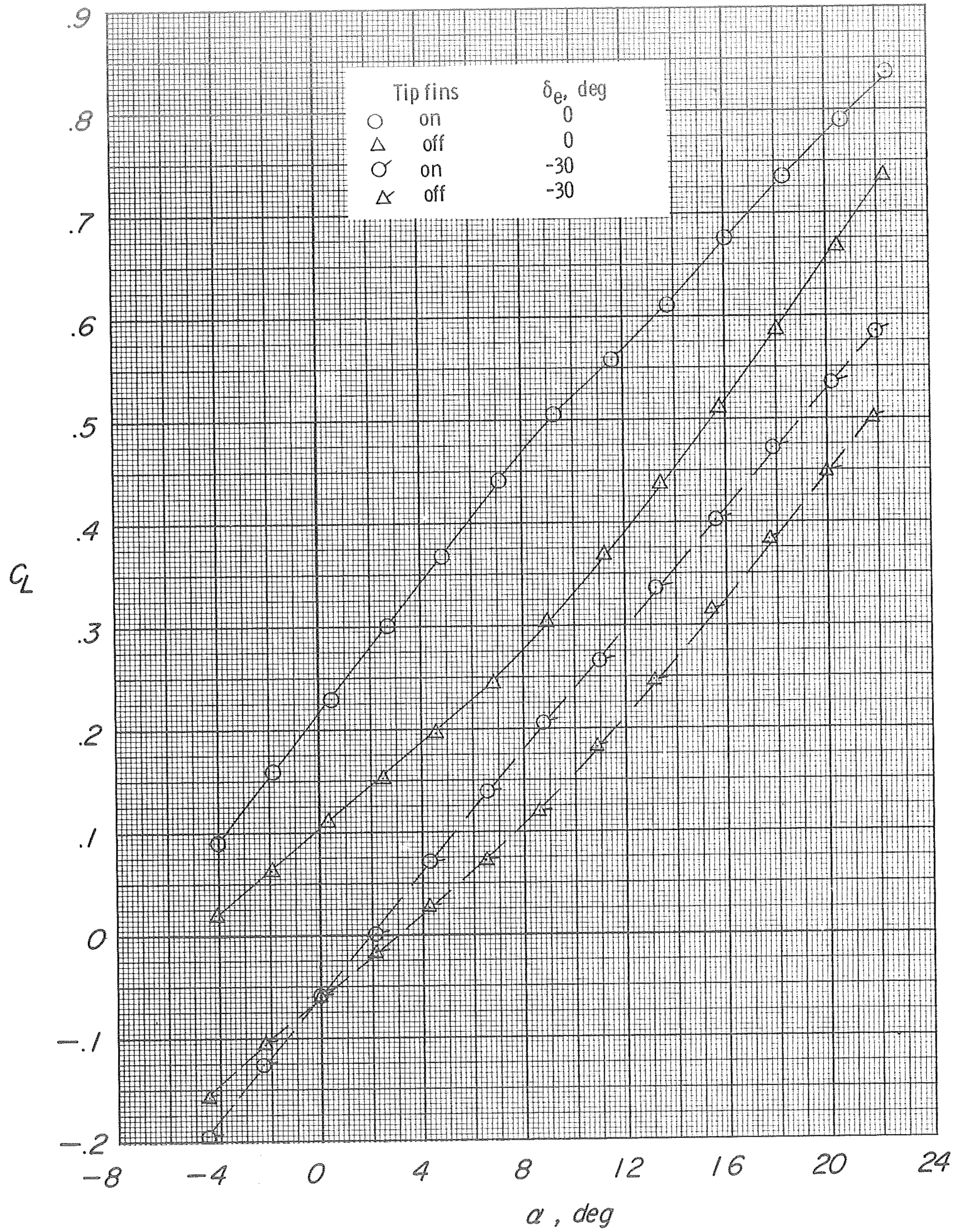
(c) L/D and C_m versus α.

Figure 6.- Continued.



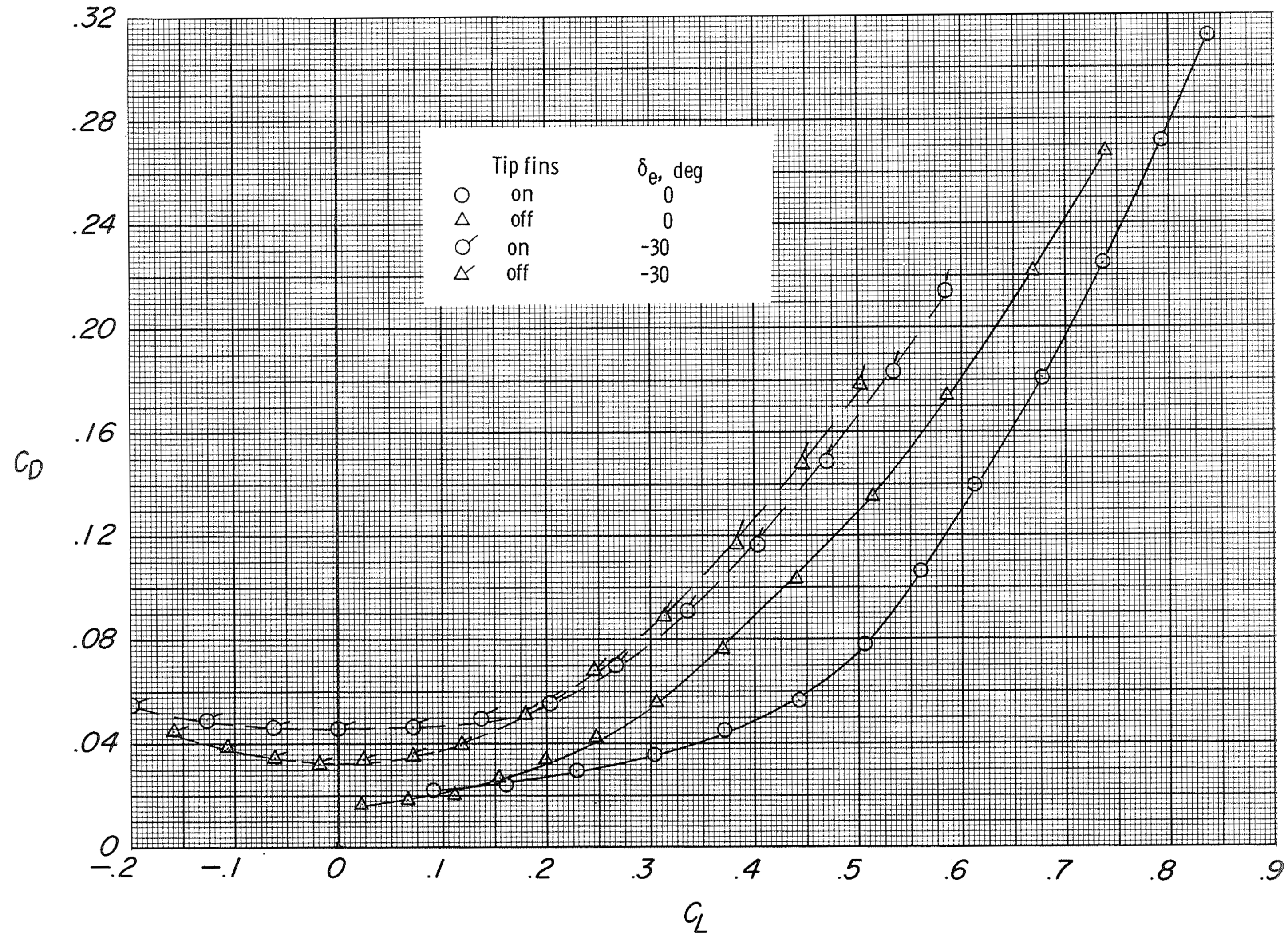
(d) L/D and C_m versus C_L.

Figure 6.- Concluded.



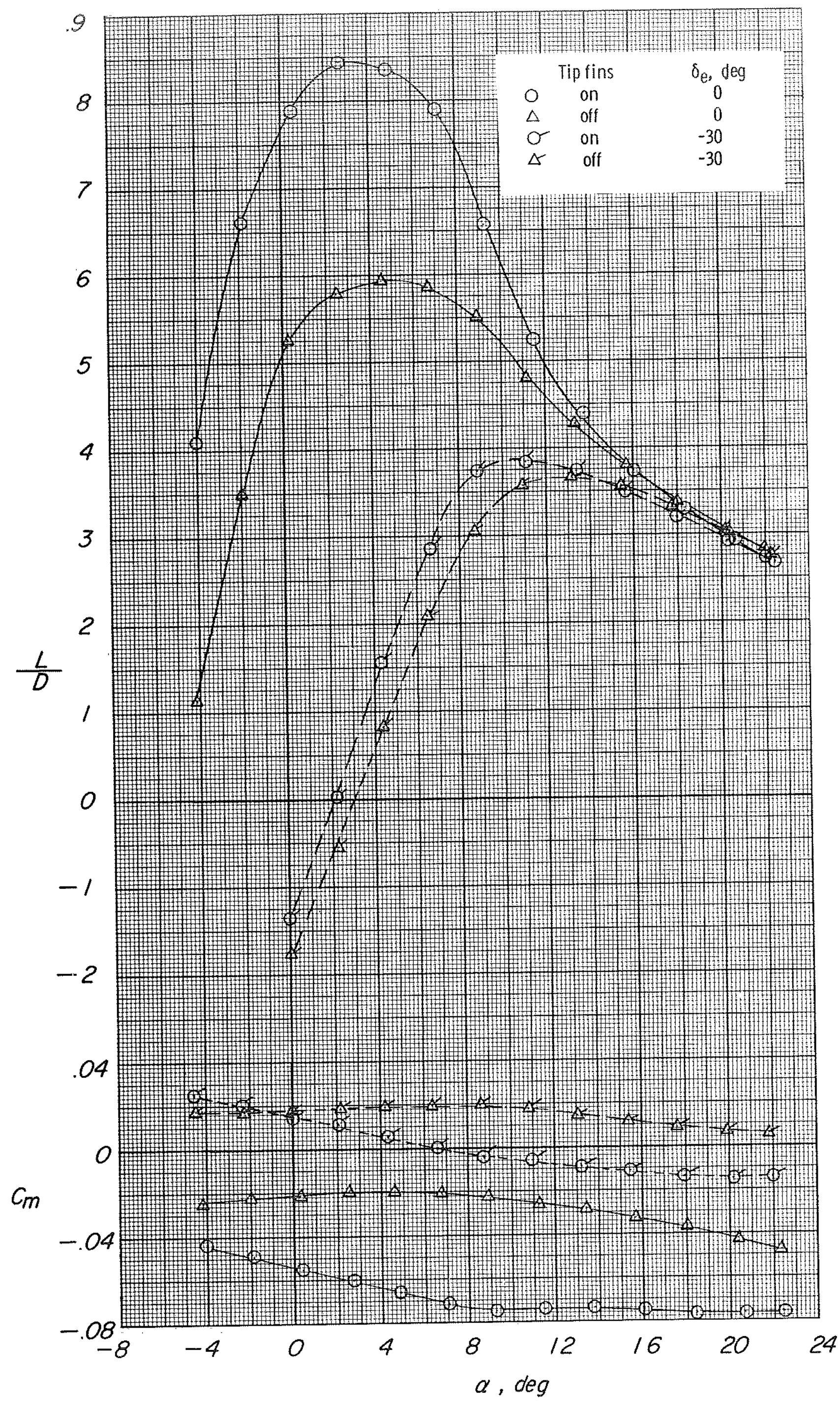
(a) Lift.

Figure 7.- Effect of tip fins on the longitudinal aerodynamic characteristics of the model. $R = 15.91 \times 10^6$.



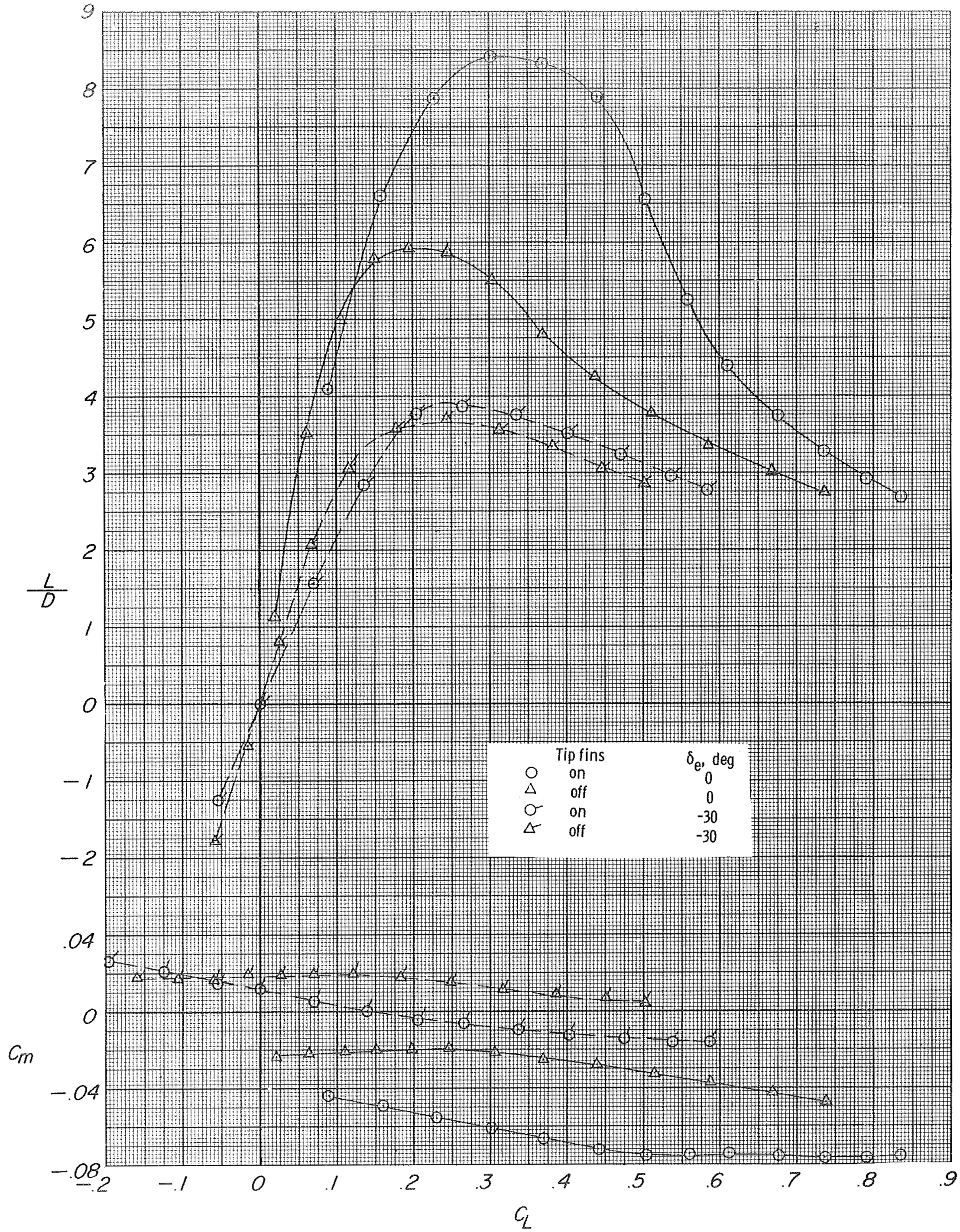
(b) Drag.

Figure 7. - Continued.



(c) L/D and C_m versus α.

Figure 7.- Continued.



(d) L/D and C_m versus C_L.

Figure 7.- Concluded.

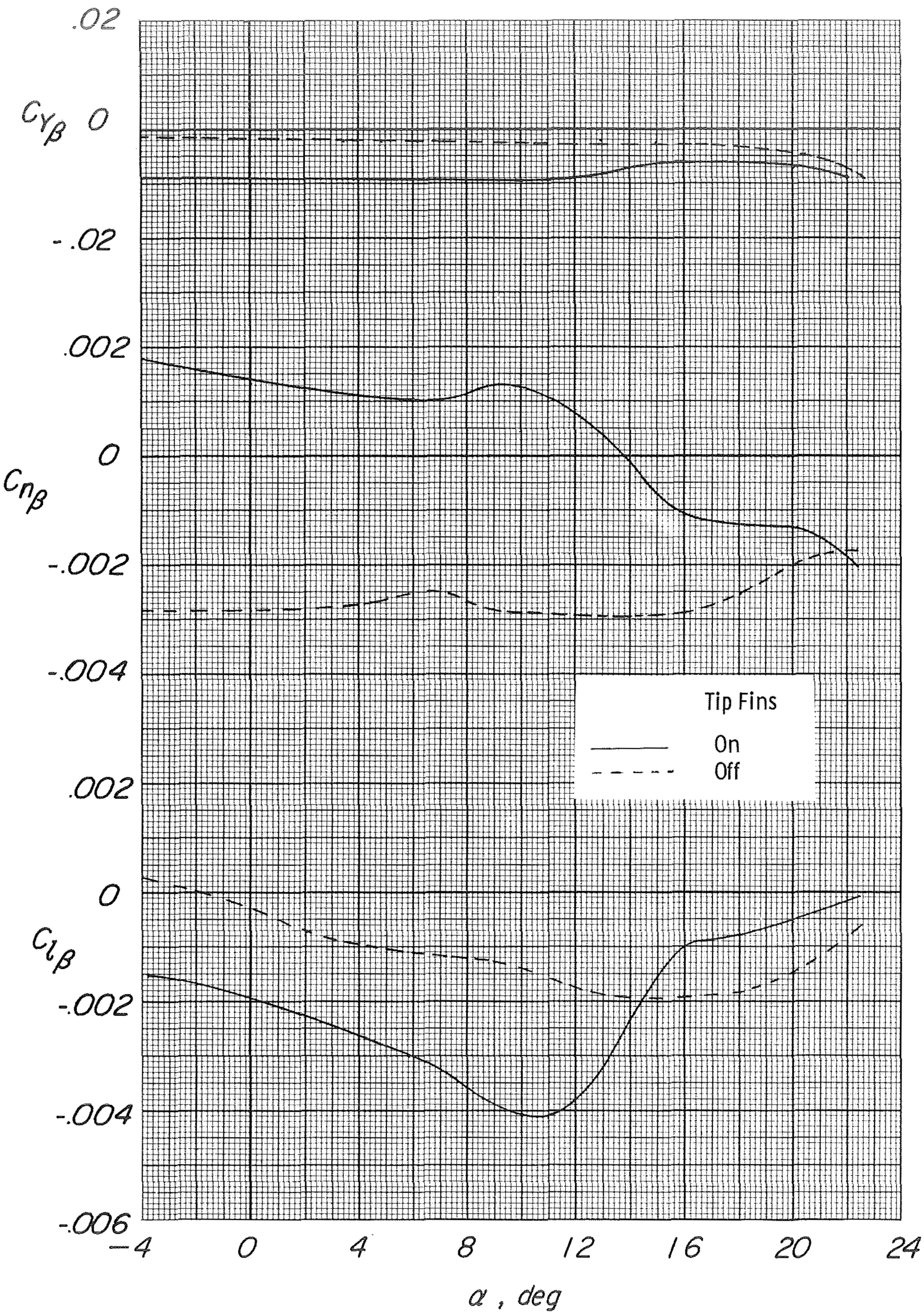


Figure 8.- Static lateral stability parameters of the model. $\delta_e = 0^{\circ}$; $R = 15.91 \times 10^6$.

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